

# On the effects of rotation during the formation of population III protostars

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## Abstract.

It has been suggested that turbulent motions are responsible for the transport of angular momentum during the formation of Pop. III stars, however the exact details of this process have never been studied. We report the results from three dimensional SPH simulations of a rotating self-gravitating primordial molecular cloud, in which the initial velocity of solid-body rotation has been changed. We also examine the build-up of the discs that form in these idealized calculations.

**Keywords:** stars formation – hydrodynamics – instabilities – angular momentum

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## MODEL PARAMETERS

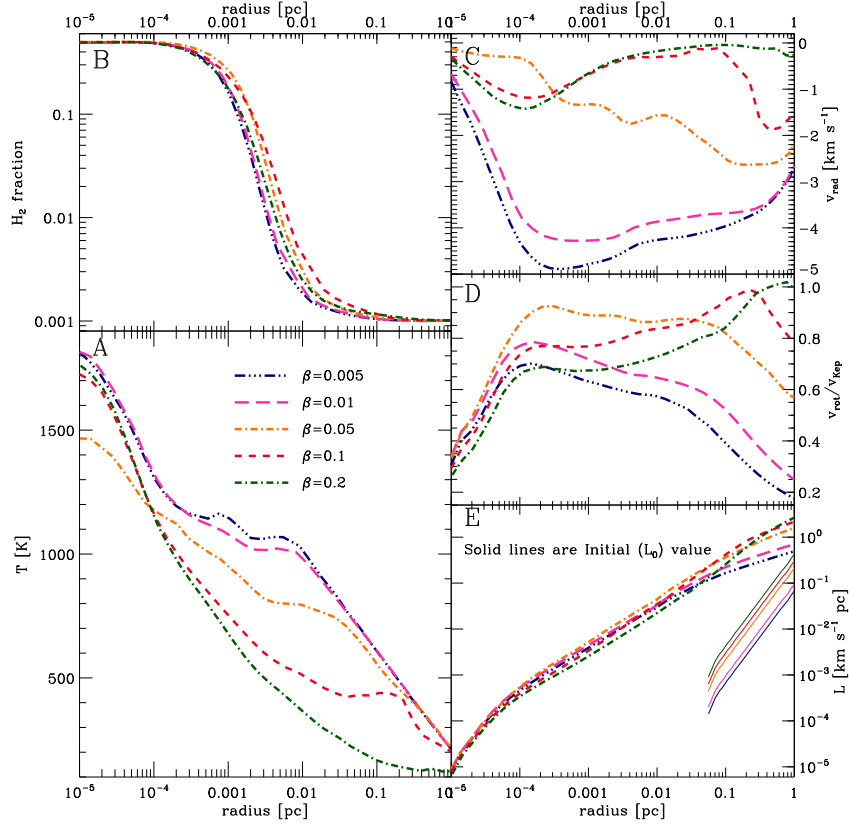
The Pop. III simulations start with a number density of  $10^3 \text{ cm}^{-3}$ , with a temperature of 250 K and contain 2 Jeans masses with total mass  $M \sim 2982 M_{\odot}$  of gas. Our clouds are given different levels of rotational support, described via the  $\beta$ -parameter defined as

$$\beta = \frac{\text{Rotational Energy}}{\text{Gravitational Energy}} = \frac{R_0^3 \Omega^2}{3GM} = 0.005, 0.01, 0.05, 0.1, 0.2,$$

where  $\Omega$  is the angular velocity. The clouds are all modeled using 5,000,000 SPH particles. The initial density( $\rho$ ) is uniform, with the  $t_{ff} = 1.37 \text{ Myr}$  and  $t_{\text{sound}} = 5 \text{ Myr}$ .

## POWER-LAW ANGULAR MOMENTUM PROFILE

- Similar  $\text{H}_2$ -fractions for different  $\beta$  suggest that the collapsed clouds subject to compressional heating rather than just the  $\text{H}_2$  formation heating. A lower rate of compressional heating implies a lower radial velocity, and is consistent with higher degree of rotational support [1],[2].
- Even though our initial conditions lack any turbulence and are very different from fully self-consistent cosmological initial conditions, we find the characteristic power-law angular momentum( $L$ ) profile that has been reported in several studies, suggesting *universal* collapse property.  $L_0 \propto r^2$  (initially) and  $L \propto r$  (power-law).
- The origin of the slope is just the cloud getting rid of excess angular momentum while trying to collapse (with  $\rho(r) \propto r^{-2.2}$ ) and thus dragging the remaining angular momentum along for the ride.



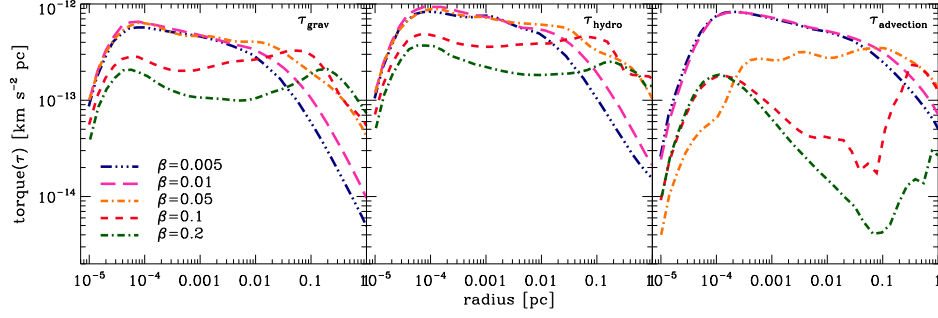
**FIGURE 1.** Radially binned, mass-weighted averages of physical quantities related to the angular momentum of the gas for five different  $\beta$ , compared when the gas density reaches  $\sim 5 \times 10^{-10} \text{ g cm}^{-3}$ .

## RELATIVE STRENGTH OF TORQUES

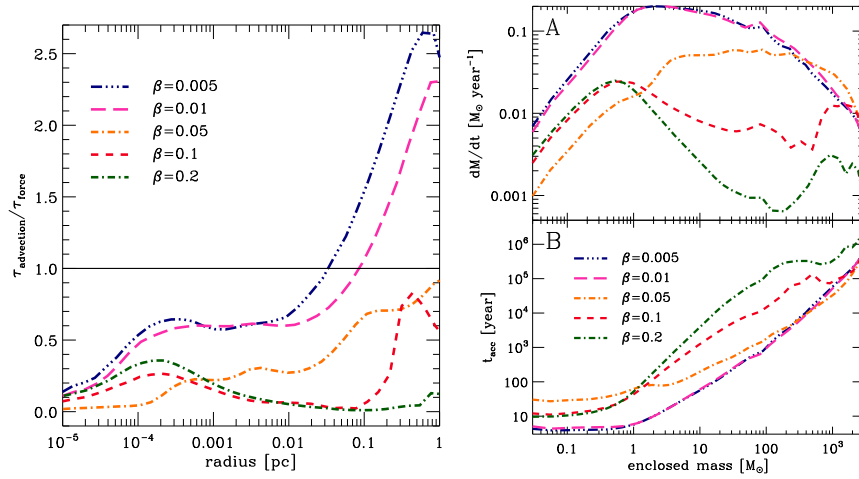
Gravitational torque is always less than the hydro torque. The non-axisymmetric nature of the cloud and the spiral arms are caused by the gravitational instability [3]. Yet the resulting torques are not dominated by the gravitational force itself, but rather the non-axisymmetric pressure forces that arise from the structure. Hence transport is *local* [4], even though it is induced by a global phenomenon. In the outer regime the transfer of angular momentum happens because of particle's infall radially due to gravity. The Keplerian radius is larger for faster-rotating clouds. The peaks in the ratio represent the formation of consecutive discs inside the initial disc.

## ACCRETION RATE

Although the time taken to accrete the inner  $1M_{\odot}$  differs only by a factor of 10, we see that the accretion timescales for the remainder of the cloud can differ substantially, depending on the level of initial rotation. When we consider that the number of protostars also varies substantially with the spin of the cloud, we would expect the luminosity from protostellar population will also be a strong function of the cloud's rotational properties.



**FIGURE 2.** The gravitational, hydrodynamical and advective torque during star formation process.



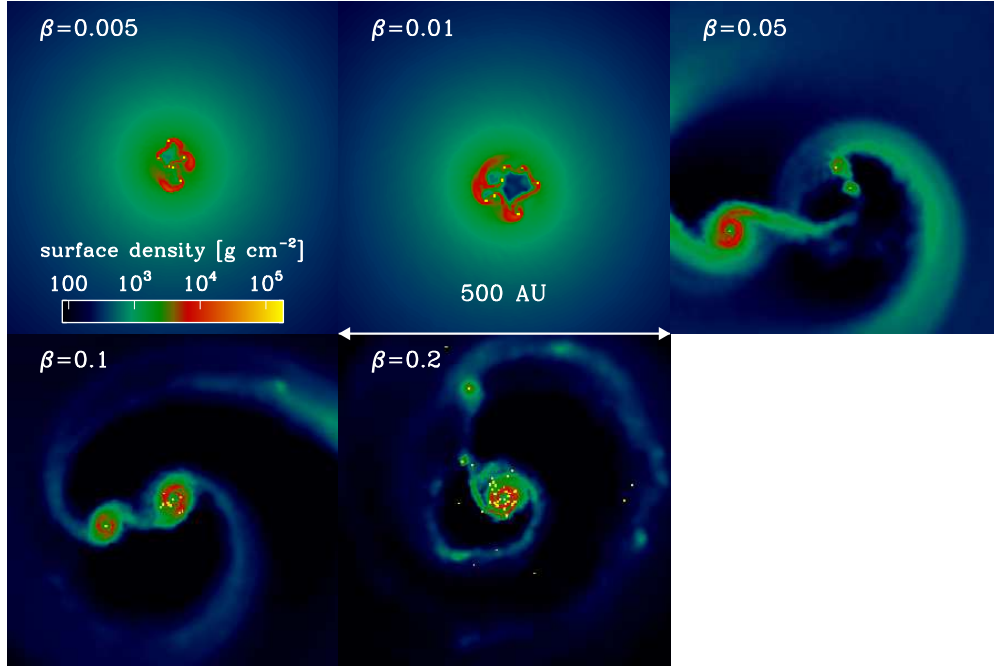
**FIGURE 3.** Relative strength of torques (*left*), accretion rate and accretion time (*right*).

## DISC FRAGMENTATION

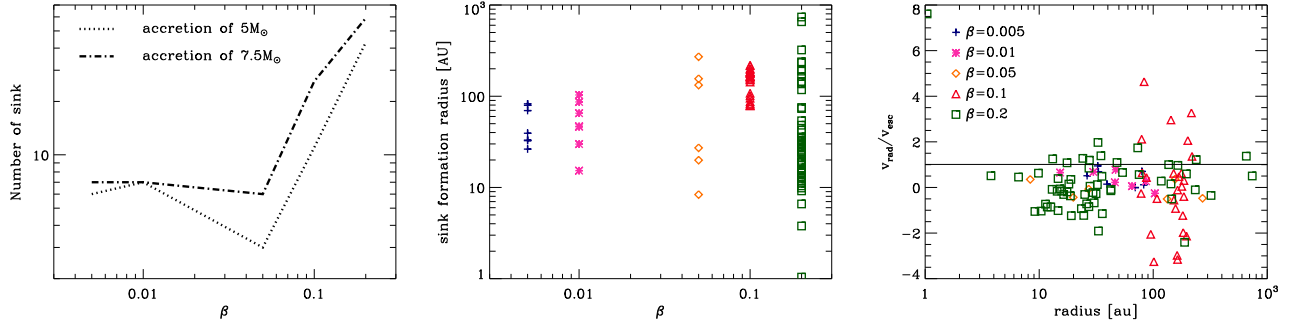
Faster-rotating clouds produce more sinks as they form rotationally supported discs much earlier than slowly-rotating clouds. A number of protostars move away from their cluster with velocity exceeding escape velocity. Though the resolution used in [5] was much higher than our resolution, we still see ejection from the cluster. Lower  $\beta$  remains in the cluster. The range of sink-formation-radius increases with  $\beta$ , except for  $\beta = 0.1$ .

## CONCLUSIONS

The angular momentum profile follows a power-law, regardless of initial rotation in the cloud. The transport is *local* and happens due to torques. The mass accretion rate depends on the initial level of rotation. No protostars with  $\beta = 0.1$  form within the central 100 AU. The faster rotating clouds escape from the cluster, might stop accreting and enter the main sequence as low mass Pop. III stars.



**FIGURE 4.** Surface density in 500 AU around first protostar as the young stellar system gains mass.



**FIGURE 5.** Number of sink particles and their escape velocities during the disc fragmentation.

## ACKNOWLEDGMENTS

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